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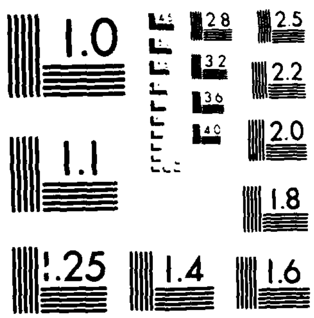

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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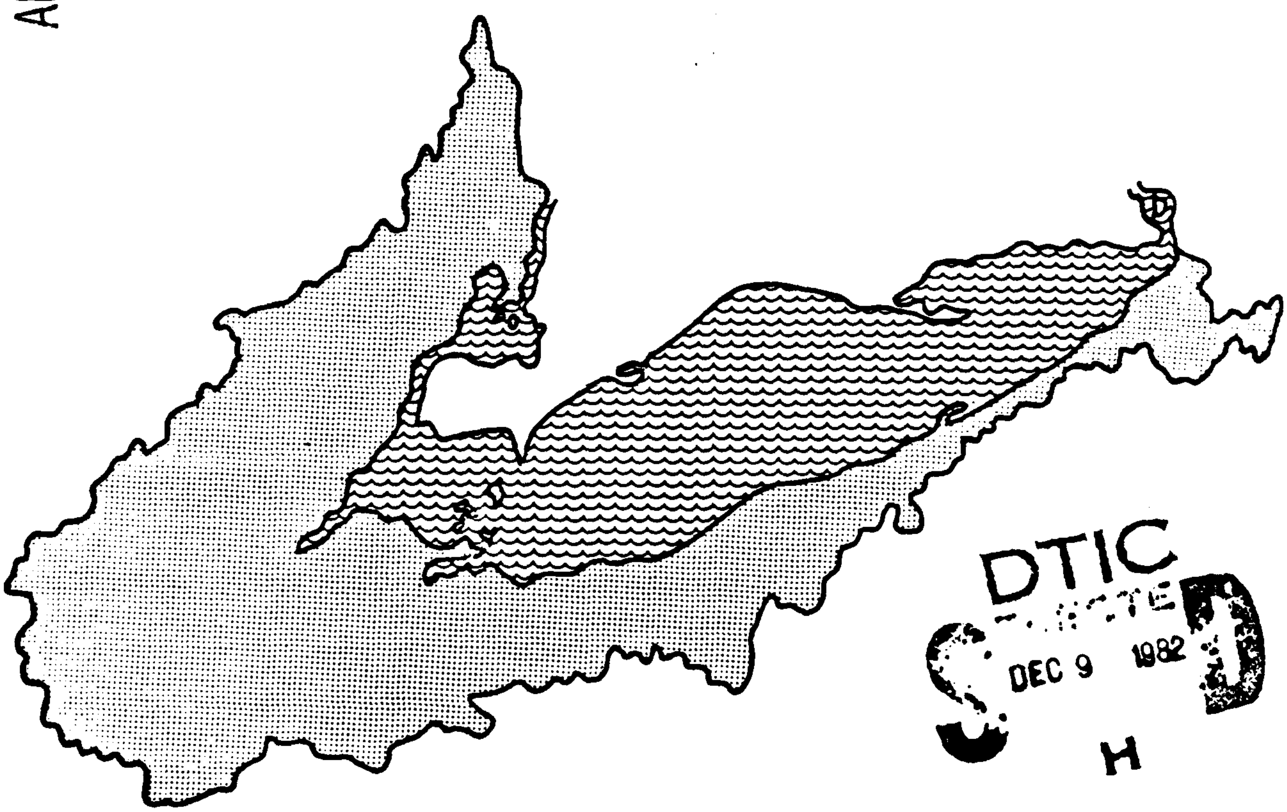
ALTERNATIVE MANAGEMENT OPTIONS FOR THE CONTROL OF DIFFUSE PHOSPHORUS LOADS TO LAKE ERIE



LAKE ERIE WASTEWATER MANAGEMENT STUDY

US Army Corps of Engineers
Buffalo District

SEPTEMBER 1982

The dissolved and pariculate phosphate load reduction which could be obtained by reducing available P in agriculture soils from their 1980 levels down to the suffinciency level for corn and soybean were estimated for the Ohio and Michigan Lake Erie Basin counties. Reductions were small compared to the reductions which could be achieved with conservation tillage, but could become more significant if available phosphorus levels in Basin agriculture soils continue to rise.

The costs and phosphorus reductions obtainable with a side range range of agriculture management practices were compared. Conservation tillage offered the most cost-effective means of greatly reducing the agriculture diffuse phosphorus load to Lake Erie.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Available phosphorus soil test levels in Ohio and Michigan agriculture soils have increased steadily since the 1960's. These increases are reported here, by county, for those counties in the Lake Erie Basin of these two states.

An economic analysis of phosphate fertilizer use in Ohio Lake Erie Basin counties for corn, soybeans and wheat, shows that there is an overuse of phosphate on corn and insufficient P fertilization of soybeans. P fertilizer use on wheat is at the economic optimum .

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ALTERNATIVE MANAGEMENT OPTIONS FOR THE CONTROL OF DIFFUSE PHOSPHORUS LOADS TO LAKE ERIE

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November 1982

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ABSTRACT

Available phosphorus soil test levels in Ohio and Michigan agricultural soils have increased steadily since the 1960's. These increases are reported here, by county, for those counties in the Lake Erie Basin of these two states.

An economic analysis of phosphate fertilizer use in Ohio Lake Erie Basin counties for corn, soybeans and wheat, shows that there is an overuse of phosphate on corn and insufficient P fertilization of soybeans. P fertilizer use on wheat is at the economic optimum.

The dissolved and particulate phosphate load reductions which could be obtained by reducing available P in agricultural soils from their 1980 levels down to the sufficiency level for corn and soybeans were estimated for the Ohio and Michigan Lake Erie Basin counties. Reductions were small compared to the reductions which could be achieved with conservation tillage, but could become more significant if available phosphorus levels in Basin agricultural soils continue to rise.

The costs and phosphorus reductions obtainable with a side range of agricultural management practices were compared. Conservation tillage offered the most cost-effective means of greatly reducing the agricultural diffuse phosphorus load to Lake Erie.

INTRODUCTION

The Army Corps of Engineers Lake Erie Wastewater Management Study (LEWMS) in their five year study of phosphorus loadings to Lake Erie have identified rural diffuse phosphorus loads as a major contribution to the total P load entering the Lake. They concluded (COE, 1979) that significant reductions in the rural diffuse total phosphorus load could be achieved by a high degree of implementation of conservation tillage on suitable soils throughout the Basin. Forster (1978) found that implementation of conservation tillage on suitable soils would have little or no negative economic impact on farm income, and on some soils, farm income would actually increase. The costs of an accelerated implementation program will be those of the demonstration/technical assistance/cost-sharing efforts in individual counties.

Logan and Adams (1981) examined the literature on effectiveness of conservation tillage in reducing particulate and dissolved phosphorus loads in surface runoff. These practices were found to be highly effective in reducing particulate P losses, but had no effect on dissolved P. In fact, they found that, in all cases, dissolved P loads increased with conservation tillage. Logan and Adams (1981) also indicated that dissolved P loads were related to the levels of available P in soils and the methods of application of phosphate fertilizer. Levels of Bray P1 available P in Ohio and Michigan Lake Erie Basin soils had been shown by Logan (1977) to have increased rapidly in the period 1961-1976. These factors indicated that a phosphate fertility management program might have a significant effect on the loads of dissolved phosphorus to Lake Erie.

Other practices are used to varying extents in the Lake Erie Basin for erosion control and nutrient loss reductions. Practices such as livestock waste management, grassed waterway, tile drainage and others will control to greater or lesser degrees sediments and/or nutrients, and their effects in reducing rural diffuse phosphorus loads to Lake Erie were examined in this report.

The specific objectives of this report were to:

1. Determine the changes in Bray P1 available P levels in Ohio and Michigan Lake Erie Basin counties from 1961 to 1980.
2. Estimate the potential reductions in dissolved and particulate phosphorus loads with a fertility management program.
3. Determine the economic optimum levels of P fertilization in the Lake Erie counties of Ohio.
4. Estimate the costs and effectiveness of alternative management practices for the reduction of rural diffuse phosphorus loads.

LEVELS OF AVAILABLE PHOSPHORUS IN OHIO AND MICHIGAN LAKE ERIE BASIN SOILS

Logan (1977) has previously reported on levels of Bray P1 available phosphorus in Lake Erie Basin agricultural soils using soil test summary data from the state soil test laboratories. He found that levels have been climbing steadily in Ohio since 1961 when data were first reported, and levels in Michigan soils showed a similar trend. In Ontario, however, levels have remained quite steady and this difference was attributed to differences in P fertilizer recommendations between Ontario and Ohio/Michigan. These two U.S. states recommend an annual maintenance application of phosphate even when soil test levels are well above the sufficiency level--the level at which crops no longer respond to added phosphate. No soil test summary data were attainable from New York, Pennsylvania or Indiana, but these states only represent a small percentage of the total cropland acreage in the Lake Erie Basin.

The soil test summary data has been updated to 1980. Table 1 gives the percentage of soil samples testing in different ranges by county for 1971, 1976 and 1980. The same data for the Northwest Ohio counties are presented graphically in Figure 1 and the Northeast Ohio counties in Figure 2. Samples testing in the low ranges have dropped steadily in the period 1971-1980 while those in the highest ranges have increased steadily. The highest percentage of samples, however, tested in the sufficiency range in all three years. Figures 3 and 4 give the mean values for the Northwest and Northeast Ohio counties, respectively, in 1961, 1971, 1976 and 1980, and show that the mean available phosphorus levels have increased markedly in this period.

Table 2 gives the percentage of soil samples testing in different ranges for Michigan counties in 1962-1980. This data is also presented graphically in Figure 5. The trends are similar to those seen in Ohio. The Michigan data is partitioned into more ranges at the high end of the scale, and point out the numbers of samples testing at very high levels. The Michigan counties in 1980, for example, had anywhere from 2.7 to 16.4% of all samples testing above 300 pounds available P/acre.

Since many of the Lake Erie Basin agricultural soils are testing higher than they need to be, a fertility management strategy was developed which would reduce, over time, soil test levels above the sufficiency level for corn and soybeans back down to the sufficiency level.

PHOSPHORUS REDUCTIONS WITH FERTILITY MANAGEMENT

Available phosphorus levels in agricultural soils in Michigan and Ohio have increased steadily in the last two decades (Figures 1-5) and today many soils have levels that are higher than that required for economic yield increases. Any

Table 1. **Percentage distribution of soil test samples by Bray P1 available P range (pounds P/acre) in Ohio counties draining into Lake Erie (1971-1980).**

County	Year	Range in Phosphorus Levels (pounds P/acre) <10	10-19	20-29	30-39	60-89	>89
		% of samples					
		Maumee-Portage-Sandusky Basin					
Allen	1971	5	19	24	42	8	3
	1976	1	12	15	46	20	7
	1980	0	4	19	35	23	18
Auglaize	1971	6	25	25	33	8	[illegible]
	1976	2	11	20	43	18	5
	1980	1	4	11	40	25	19
Crawford	1971	6	22	22	36	12	3
	1976	2	10	19	48	13	8
	1980	0	2	12	50	25	10
Defiance	1971	9	20	26	30	11	5
	1976	4	16	18	40	13	9
	1980	2	6	15	37	16	24
Fulton	1971	1	5	8	35	31	21
	1976	0	2	7	26	34	32
	1980	1	2	2	19	17	60
Hancock	1971	2	14	22	40	16	6
	1976	1	9	14	47	21	9
	1980	0	6	10	38	23	22
Hardin	1971	4	21	20	35	13	8
	1976	2	17	20	47	11	4
	1980	1	3	11	51	23	11
Henry	1971	1	10	20	36	19	14
	1976	0	6	7	42	29	16
	1980	0	2	4	30	25	39

County	Year	Range in Phosphorus Levels (pounds P/acre) <10	10-19	20-29	30-39	60-89	>89
		% of samples					
		Maumee-Portage-Sandusky Basin					
Lucas	1971	2	7	10	33	23	26
	1976	1	6	7	30	26	30
	1980	0	2	6	31	15	45
Marion	1971	7	23	24	35	9	3
	1976	2	13	21	44	14	7
	1980	1	5	12	43	22	17
Mercer	1971	5	22	20	38	11	3
	1976	1	10	14	46	18	10
	1980	0	2	8	39	25	25
Ottawa	1971	7	31	15	16	12	9
	1976	2	8	15	31	29	15
	1980	0	2	9	37	18	34
Paulding	1971	8	34	23	27	6	3
	1976	4	24	26	38	5	3
	1980	0	10	26	44	8	9
Putnam	1971	4	13	16	36	18	13
	1976	1	5	17	43	21	13
	1980	1	6	13	43	16	21
Sandusky	1971	5	11	15	34	21	14
	1976	3	9	12	30	27	19
	1980	2	4	8	34	24	28
Seneca	1971	7	23	19	33	12	6
	1976	2	16	22	42	13	3
	1980	1	6	12	35	19	29
Van Wert	1971	3	14	22	44	13	4
	1976	2	17	16	50	10	6
	1980	0	6	10	52	16	15

County	Year	Range in Phosphorus Levels (pounds P/acre)					
		<10	10-19	20-29	30-39	60-89	>89
		% of samples					
		Maumee-Portage-Sandusky Basin					
Williams	1971	3	15	20	38	17	7
	1976	2	11	17	41	19	11
	1980	1	5	8	41	21	25
Wood	1971	5	10	15	38	20	12
	1976	1	6	13	47	23	9
	1980	1	5	13	43	18	21
Wyandot	1971	6	17	24	39	11	4
	1976	2	12	18	43	17	8
	1980	0	4	15	45	25	10
		N. E. Ohio (Lake Erie Drainage Basin)					
Ashland	1971	6	24	21	34	11	4
	1976	5	19	19	33	15	10
	1980	1	6	13	36	20	24
Ashtabula	1971	24	26	16	22	9	3
	1976	19	27	16	27	8	3
	1980	7	18	16	30	16	13
Erie	1971	8	14	19	38	16	4
	1976	5	11	16	31	24	13
	1980	2	5	14	33	20	26
Geauga	1971	18	23	16	30	9	3
	1976	11	27	20	27	12	4
	1980	6	24	17	32	12	9
Huron	1971	9	21	17	22	7	24
	1976	5	19	18	32	9	16
	1980	1	8	14	34	13	29

County	Year	Range in Phosphorus Levels (pounds P/acre) <10	10-19	20-29	30-39	60-89	>89
		% of samples					
		N. E. Ohio (Lake Erie Drainage Basin)					
Lake	1971	17	11	13	19	13	26
	1976	14	29	10	10	22	14
	1980	0	15	7	32	15	32
Lorain	1971	16	32	23	22	5	2
	1976	9	28	19	34	5	4
	1980	4	16	20	31	16	14
Portage	1971	12	20	17	32	12	6
	1976	8	19	19	30	14	9
	1980	2	10	15	30	18	27
Summit	1971	13	17	13	24	11	11
	1976	6	13	13	33	19	16
	1980	8	5	11	33	20	22
Trumbull	1971	13	25	17	29	13	4
	1976	12	27	15	32	8	5
	1980	6	13	13	26	20	22

Table 2. Percentage distribution of soil test samples by Bray P1 available P range (pounds P/acre) in Michigan counties draining into Lake Erie (1962-1980).

County	Year	Range in Phosphorus Levels (pounds/acre) % of samples								
		0-9	10-19	20-39	40-69	70-99	100-149	150-199	200-299	>300
Hillsdale	1962	0.0	33.3	16.7	33.3	16.7	0.0	0.0	0.0	0.0
	1967	13.3	33.3	26.7	6.7	0.0	13.3	6.7	0.0	0.0
	1970	3.2	16.1	19.4	25.8	22.6	12.9	0.0	0.0	0.0
	1975	0.0	3.7	14.8	29.6	3.7	22.2	7.4	11.1	7.4
	1976	0.0	8.6	17.1	42.9	11.4	8.6	2.9	5.7	2.9
	1980	0.0	1.3	8.0	22.7	17.3	22.7	16.0	9.3	2.7
Lapeer	1962	16.7	29.6	33.6	12.6	4.8	2.2	0.4	0.0	0.0
	1967	22.5	28.8	30.4	12.9	3.0	1.8	0.4	0.2	0.0
	1970	9.8	19.5	28.9	25.4	10.2	4.3	0.8	0.8	0.4
	1975	3.4	13.3	37.2	21.8	9.2	7.2	2.4	4.4	1.0
	1976	7.4	13.9	24.3	30.9	11.3	6.5	3.5	2.2	0.0
	1980	6.0	9.6	18.9	22.8	13.8	13.2	3.3	6.3	6.0
Lenawee	1962	11.1	33.3	24.4	20.0	6.7	4.4	0.0	0.0	0.0
	1967	9.7	20.2	28.3	18.4	9.2	6.6	5.2	1.6	0.8
	1970	5.7	36.8	25.3	17.2	4.6	4.6	2.3	1.1	2.3
	1975	4.7	7.6	18.6	27.1	12.0	13.6	6.0	6.9	3.5
	1976	6.7	21.9	19.0	20.0	6.7	9.5	8.6	2.9	3.8
	1980	1.0	4.8	15.7	25.2	8.6	14.8	7.1	14.3	8.6
Livingston	1962	12.5	18.8	12.5	50.0	0.0	0.0	6.3	0.0	0.0
	1967	9.2	20.1	32.2	26.4	7.1	3.3	1.7	0.0	0.0
	1970	6.3	12.3	34.3	30.1	9.9	5.1	0.9	0.6	0.3
	1975	3.6	7.5	26.2	28.2	19.0	8.2	3.0	1.0	3.3
	1976	7.0	13.1	26.6	22.5	17.2	7.4	3.7	2.5	0.0
	1980	1.6	1.6	8.4	22.7	16.5	22.4	7.5	8.7	10.6
Macomb	1962	15.4	16.2	17.1	14.5	13.7	13.7	7.7	1.7	0.0
	1967	6.0	15.3	19.7	16.4	10.4	8.7	8.2	4.4	10.9
	1970	13.1	19.7	19.7	17.8	10.0	9.3	4.2	1.9	4.2
	1975	5.3	15.6	18.9	15.6	9.5	10.6	5.8	9.7	8.9
	1976	6.6	12.8	21.4	12.1	8.3	12.8	5.2	13.8	7.2
	1980	2.8	5.8	13.9	21.9	12.3	10.3	8.3	9.6	15.1

County	Year	Range in Phosphorus Levels (pounds P/acre)								
		0-9	10-19	20-39	40-69	70-99	100-149	150-199	200-299	>300
		% of samples								
Monroe	1962	14.3	0.0	19.0	26.2	19.0	14.3	7.1	0.0	0.0
	1967	2.4	9.6	28.9	33.7	6.0	4.8	8.4	4.8	1.2
	1970	4.8	21.0	28.6	24.8	6.7	8.6	3.8	1.9	0.0
	1975	3.6	7.3	24.2	24.2	15.2	11.5	7.3	5.5	1.2
	1976	5.3	9.6	14.0	28.1	16.7	13.2	0.9	7.9	4.4
	1980	4.0	2.3	7.5	20.2	12.2	19.7	10.4	15.0	8.7
Oakland	1962	9.4	7.5	28.3	30.2	15.1	9.4	0.0	0.0	0.0
	1967	8.1	9.9	20.7	25.2	21.6	8.1	5.4	0.9	0.0
	1970	9.0	12.8	19.9	18.6	10.3	14.1	4.5	5.8	5.1
	1975	4.8	9.2	15.6	18.8	14.4	11.5	9.4	10.8	5.5
	1976	10.0	10.3	14.2	17.1	10.7	12.1	9.3	8.9	7.5
	1980	5.5	3.4	9.1	16.7	13.3	16.2	7.3	12.0	16.4
Sanilac	1962	40.9	37.9	16.4	3.8	0.6	0.4	0.0	0.0	0.0
	1967	11.1	24.4	37.9	19.8	4.7	1.5	0.3	0.2	0.1
	1970	17.2	32.9	27.1	15.1	3.7	2.2	1.1	0.5	0.1
	1975	5.0	11.9	27.8	29.3	15.5	8.2	0.7	1.2	0.5
	1976	6.0	14.1	29.6	27.6	13.1	6.4	1.7	0.9	0.6
	1980	1.6	4.7	18.1	31.2	23.2	13.2	4.2	2.6	1.1
St. Clair	1962	25.9	36.5	30.6	1.2	1.2	4.7	0.0	0.0	0.0
	1967	14.9	22.5	31.6	17.1	7.0	2.5	3.5	0.6	0.3
	1970	11.6	24.7	35.9	12.0	8.5	5.8	0.4	1.2	0.0
	1975	13.3	16.4	19.8	18.1	11.9	8.5	3.4	6.1	2.4
	1976	6.8	14.9	27.0	27.0	9.5	6.1	4.1	3.4	1.4
	1980	7.8	9.1	18.1	16.4	12.9	15.5	5.2	6.0	9.1
Washtenaw	1962	0.0	0.0	0.0	33.3	22.2	33.3	11.1	0.0	0.0
	1967	19.5	21.1	24.2	15.6	4.7	3.1	9.4	2.3	0.0
	1970	17.6	16.2	22.1	16.2	7.4	10.3	2.9	4.4	2.9
	1975	7.4	13.6	16.6	18.8	12.8	11.4	8.2	8.4	2.7
	1976	7.1	9.6	18.6	16.7	14.7	10.9	7.7	6.4	8.3
	1980	3.6	11.6	12.2	16.5	14.3	14.5	8.4	10.9	8.1
Wayne	1962	6.3	8.9	10.1	24.1	16.5	17.7	13.9	1.3	1.3
	1967	1.8	10.7	12.5	21.4	7.1	19.6	16.1	10.7	0.0
	1970	10.6	19.7	18.2	18.2	12.1	9.1	3.0	6.1	3.0
	1975	6.8	6.0	13.5	15.8	18.8	19.5	6.0	9.0	3.4
	1976	0.0	8.4	13.3	22.9	13.3	12.0	9.6	9.[illegible]	10.8
	1980	10.9	5.4	14.1	20.7	14.1	7.6	9.8	7.6	9.8

Figure 1. The percentage of agricultural soil samples testing at different ranges of Bray P1 available phosphate for Ohio counties in the NW Ohio Lake Erie Basin. Means and standard deviations shown are based on the means for the 20 counties in this region.

Distribution of Bray P1 Available P (pounds/acre) in Northwest Ohio Soils

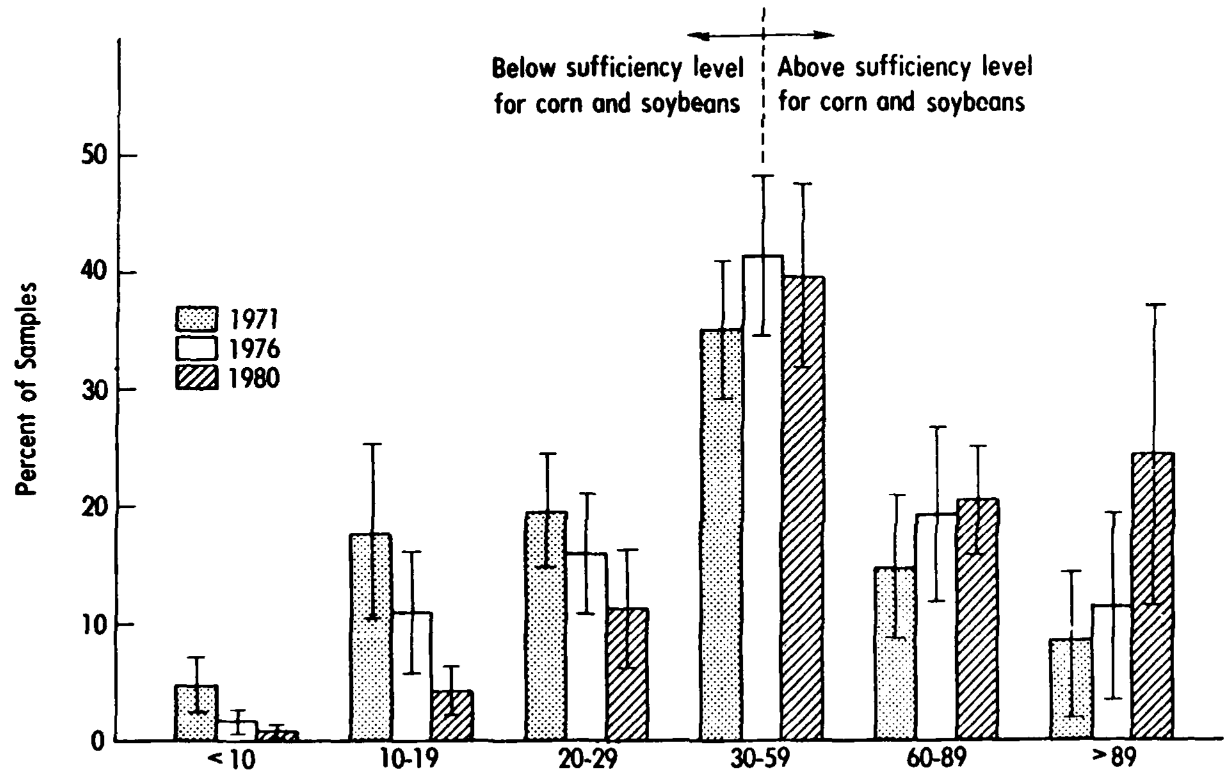


Figure 2. The percentage of agricultural soil samples testing at different ranges of Bray P1 available phosphate for Ohio counties in the NE Ohio Lake Erie Basin. Means and standard deviations shown are based on the means for the 10 counties in this region.

Distribution of Bray P1 Available P (pounds/acre) in Northeast Ohio Soils

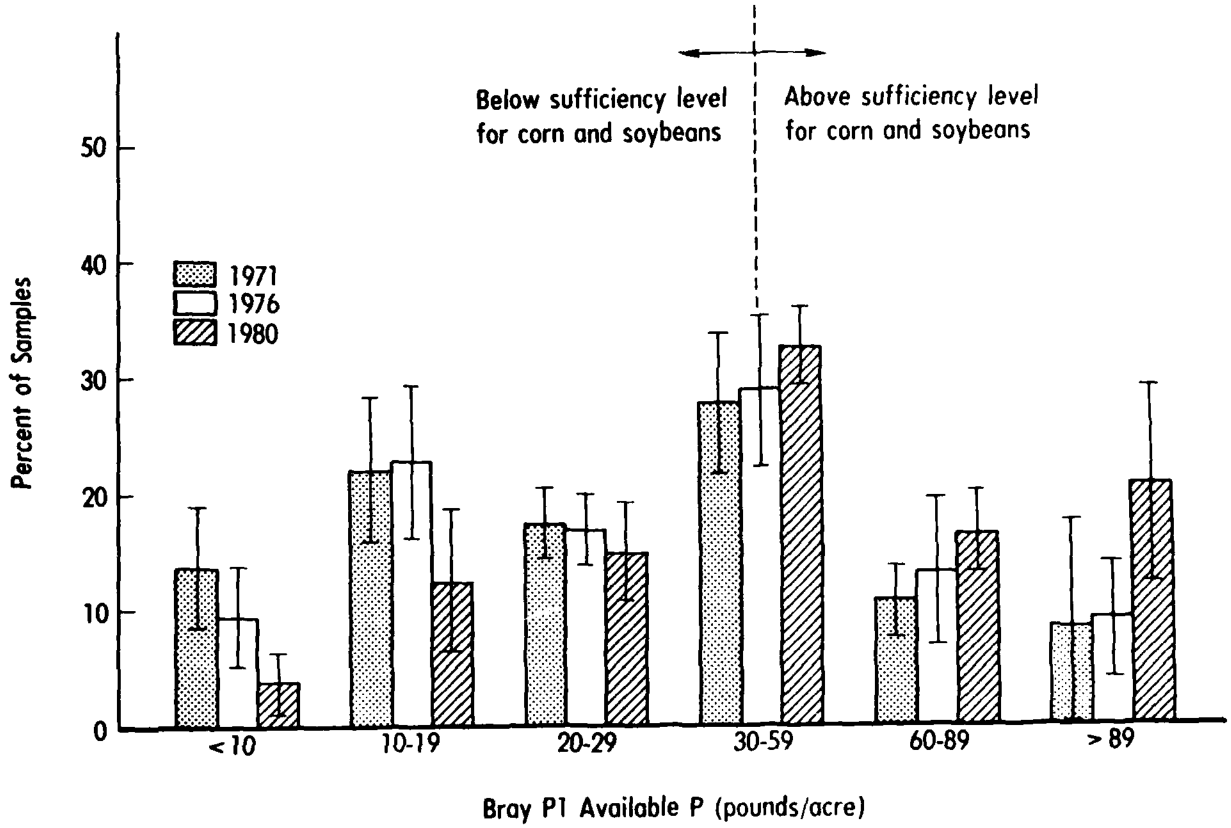


Figure 3. The trend in Bray P1 available P levels in NW Ohio agricultural soils for the period 1961-1980. Means and standard deviations are based on county means for the 20 counties in this region.

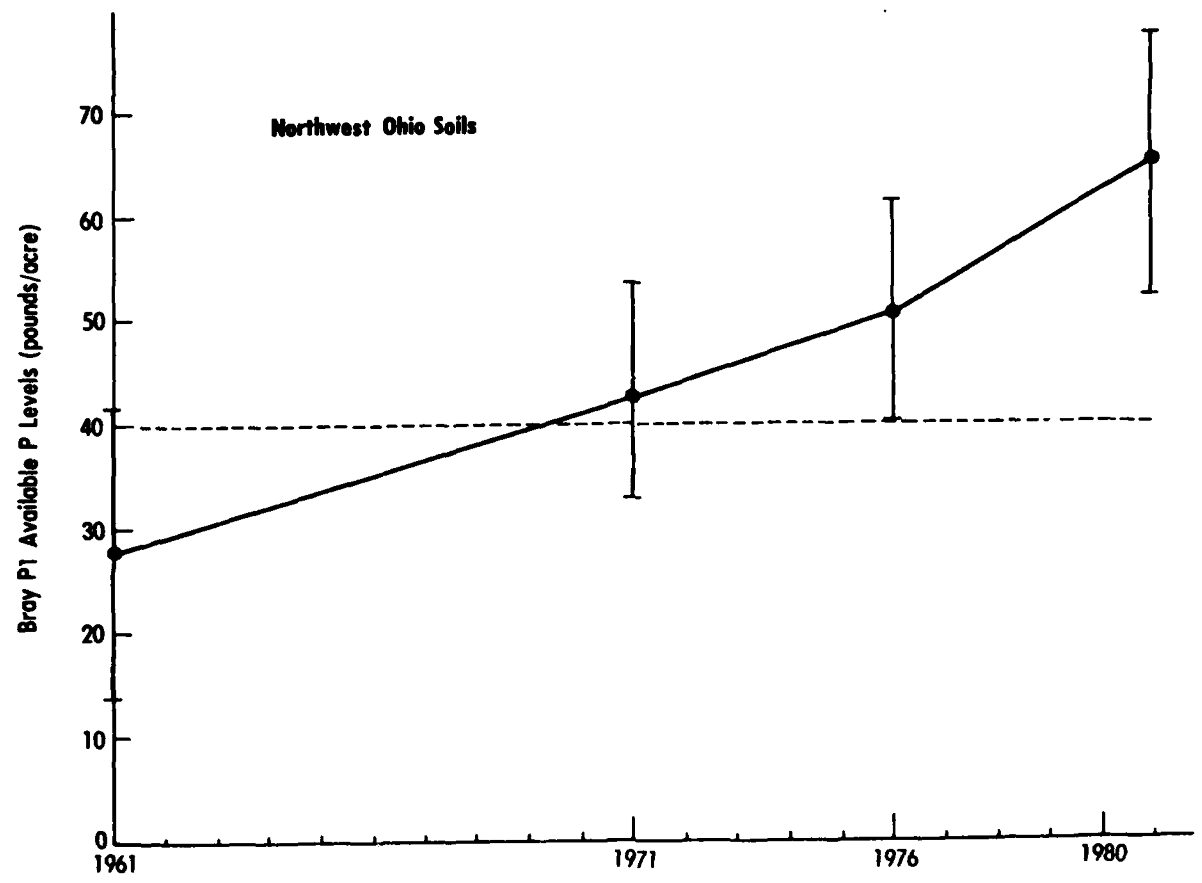

Northwest Ohio Soils
Bray P1 Available P Levels (pounds/acre)
0
10
20
30
40
50
60
70
1961
1971
1976
1980

Figure 4. The trend in Bray P1 available P levels in NE Ohio agricultural soils for the period 1961-1980. Means and standard deviations are based on county means for the 10 counties in this region.

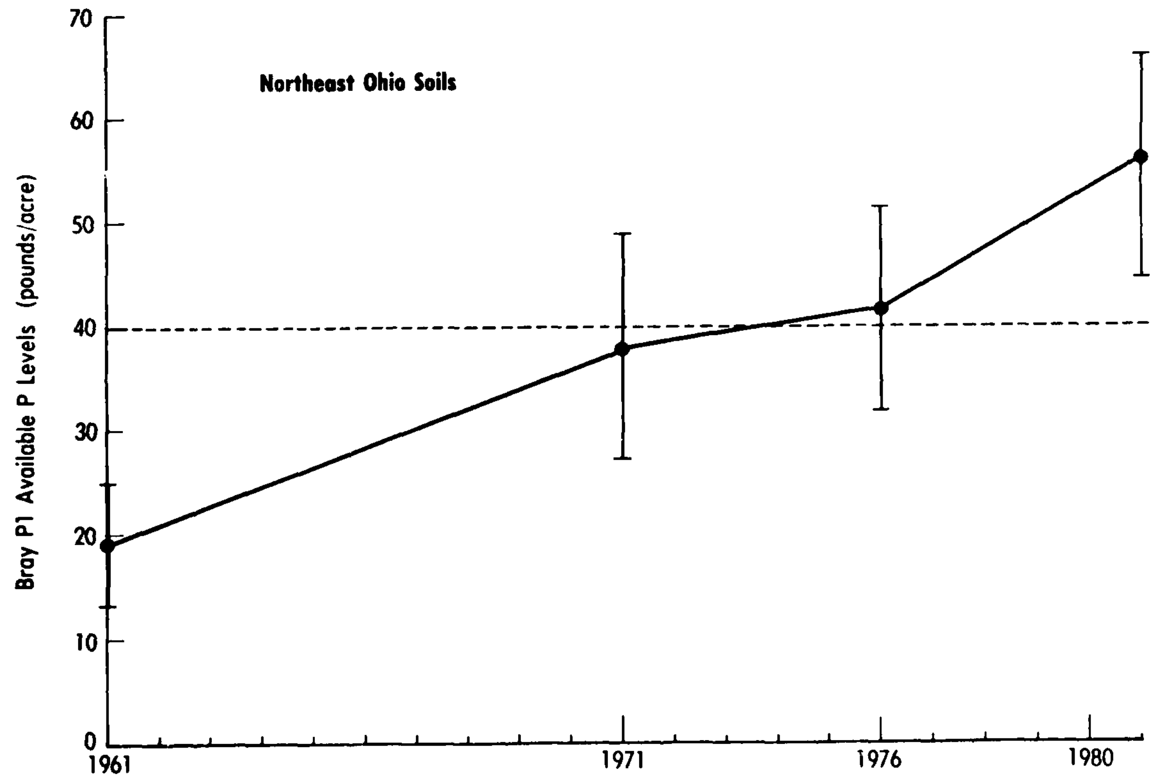
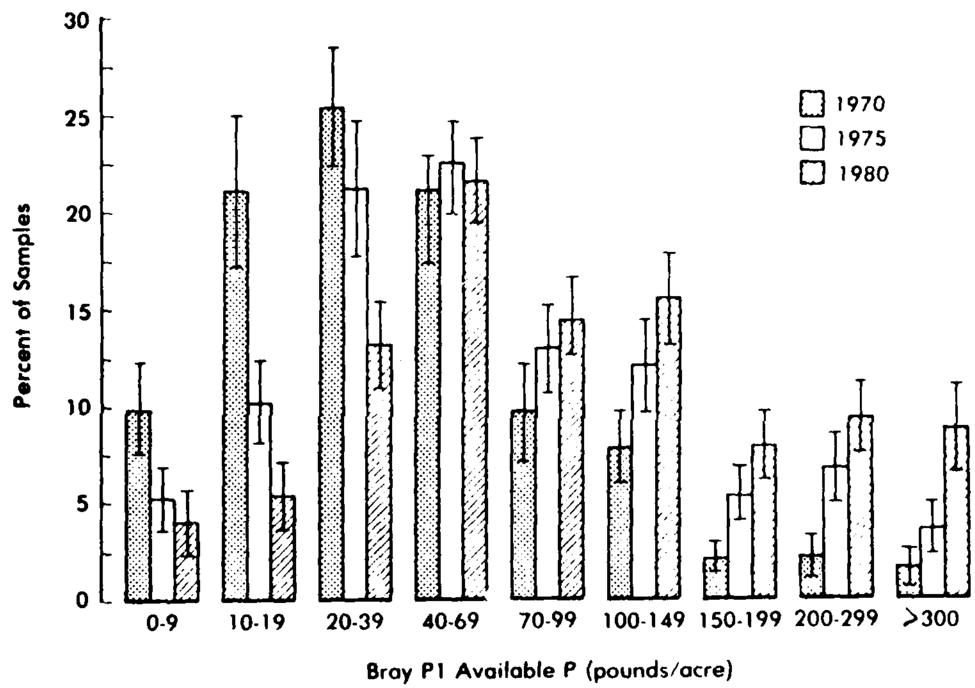

Northeast Ohio Soils
Bray P1 Available P Levels (pounds/acre)
70
60
50
40
30
20
10
0
1961
1971
1976
1980

Figure 5. The percentage of agricultural soil samples testing at different ranges of Bray P1 available phosphate for Michigan counties in the NE Ohio Lake Erie Basin. Means and standard deviations shown are based on the means for the 11 counties in this region.

Distribution of Bray P1 Available P (pounds/acre) in Michigan (L. Erie Basin) Soils



unnecessary increases in soil available phosphorus increase the potential for runoff losses of phosphate to streams and, ultimately, to Lake Erie. Romkens and Nelson (1974), Oloya and Logan (1980) and others have shown that there is a strong positive relationship between available P levels in soil and runoff losses of dissolved inorganic phosphate. In addition, unnecessary P fertilizer applications also increase the potential for particulate phosphate transport since 90% or so of applied P fertilizer becomes attached to soil particles.

With these factors in mind, a phosphate fertility management strategy was developed for the Lake Erie Drainage Basin. Only the Ohio and Michigan portions of the Basin were studied because these were the only two Basin states which had readily available statistics on soil test levels. However, these two states account for most of the agricultural land on the U.S. side of the Basin. The strategy was developed as follows:

1. The distribution of cropland soil samples testing at different ranges in 1980 was determined for each Ohio and Michigan county in the Lake Erie Basin. For calculation purposes, a mid-range value was used for each range. For example, the 15-30 μg P/g soil range was assigned a value of 22.5 μg/g. Only ranges above the crop response level of 20 μg/g for corn and soybeans was included in the analysis. The top range for Ohio is >45 μg P/g soil and this category was given a value of 45 μg/g. Likewise, the highest Michigan category of >150 μg/g was given a value of 150 μg/g. This of course underestimates the mean soil test for samples in the highest range, but no data was available for the distribution of soil test values within each range and we decided to err on the conservative side.
2. Soil fertility research in Ohio indicates that there is no yield response by corn or soybeans to phosphate fertilizer when Bray P1 available phosphorus levels in

soil are >20 μg P/g. The fertility management strategy then would allow soil tests above 20 μg/g to fall to this level over time. Research (Cox et al., 1981) has shown that soil tests will decrease with time as soils are cropped without fertilizer additions. The rate of decrease will vary with the initial soil test level, crop removal of phosphate and the retention capacity of phosphate by soil, and would be in the range of 1-20% percent a year. Therefore, achieving the desired soil test reductions will take several years, perhaps a decade.

3. The reduction in soil test levels for each range, e.g. 150 down to 20 μg/g, or 62.5 down to 20 μg/g was calculated for each county and summed for all levels for that county. This value was used to calculate reduction in dissolved and particulate phosphorus loads as follows:

   a) It was assumed, based on previous research, that 20% of fertilizer P becomes Bray P1 available P in soil while the other 80% is nonlabile. Therefore, a reduction of 10 μg P/g of Bray P1 available P should reflect a 40 μg P/g decrease in nonlabile particulate P.

   b) The nonlabile particulate P reduction is multiplied by the gross erosion for the county under existing conditions and with maximum adoption of conservation tillage as calculated by Logan et al. (1982). A 10% sediment delivery was assumed based on the work of Baker (1982).

   c) The reduction in Bray P1 available P was assumed to be equivalent to a reduction in labile sediment P. Labile sediment P should be very similar to bioavailable sediment P (Logan, 1982). It was also assumed that the labile P load would not change as erosion was reduced with conservation tillage. As erosion decreases, the enrichment of labile P on sediment increases (Logan, 1982). Enrichment is probably not great enough to fully compensate for the reduction in soil loss, and this assumption underestimates the reduction in labile P which might be achieved with conservation tillage. However, more precise predictions were not possible with the present data. A 10% delivery of gross erosion was also used to calculate labile sediment P.

d) Oloya and Logan (1980) showed that about 10% of the Bray P1 extractable phosphate in soils could be desorbed into water. This fraction was used to calculate a reduction in desorbable P as a consequence of soil test reductions. The desorbable phosphorus reduction can be equated with a reduction in the dissolved inorganic P load, and, therefore, no delivery ratio was used to calculate the load.

Table 3 gives the cropland acreage for each county, the gross erosion rates with and without maximum conservation tillage, and the percentage of cropland soil samples in the different Bray P1 available P levels. The percentages do not add to 100% because the soil test levels <27.5 μg/g are not included. Table 4 gives the phosphorus reductions in nonlabile and labile particulate P and desorbable P for each county and the sum for all counties. Fertility management would reduce annual total particulate P (nonlabile + labile particulate P) loads 79.6 metric tons with existing tillage management, and 49.1 metric tons with maximum adoption of conservation tillage. Dissolved inorganic P (as estimated by desorbable P) would decrease 1.6 metric tons. As indicated previously, these reductions will be achieved over a period of years, perhaps a decade. Without fertility management, however, the continued upward trend of cropland soil tests in the Lake Erie Basin (Figures 1-5) will increase the potential for losses of dissolved and particulate phosphate from fertilizer applied to cropland. The reductions presented here are those attributable to fertility management alone. The reduction in total particulate phosphate with conservation tillage has been estimated elsewhere.

Table 3. Cropland acreage, gross erosion and Bray P1 available P levels in Ohio and Michigan Lake Erie Basin Counties.

County	Cropland Acres	Gross Erosion: Present Conditions t/ac/yr	Gross Erosion: Present Conditions m tons/yr x10^3	Gross Erosion: Max. Conserv. Tillage t/ac/yr	Gross Erosion: Max. Conserv. Tillage m tons/yr x10^3	Percentage of Soil Samples in 1980 With the Following Mean Value of Bray P1 Available P (μg/g): 27.5	37.5	42.5	45.0	62.5	87.5	125	150
Ohio													
Allen	179783	5.4	881.51	2.2	359.13	0.0	20	0.0	7	0.0	0.0	0.0	0.0
Ashland	31046	4.2	118.40	3.0	84.57	0.0	15	0.0	10	0.0	0.0	0.0	0.0
Ashtabula	141478	1.0	128.46	0.9	115.62	0.0	8	0.0	3	0.0	0.0	0.0	0.0
Auglaize	71700	5.1	332.03	2.3	149.74	0.0	18	0.0	5	0.0	0.0	0.0	0.0
Crawford	153862	4.1	572.80	1.9	265.44	0.0	13	0.0	8	0.0	0.0	0.0	0.0
Defiance	127120	2.9	334.73	1.8	207.76	0.0	13	0.0	9	0.0	0.0	0.0	0.0
Erie	87495	2.9	230.39	1.4	111.22	0.0	24	0.0	13	0.0	0.0	0.0	0.0
Fulton	200698	2.9	528.48	1.3	236.90	0.0	34	0.0	32	0.0	0.0	0.0	0.0
Geauga	3674	1.2	4.00	0.7	2.34	0.0	12	0.0	4	0.0	0.0	0.0	0.0
Hancock	274914	3.2	798.79	1.3	324.51	0.0	21	0.0	9	0.0	0.0	0.0	0.0
Hardin	14478	3.2	42.07	1.4	18.40	0.0	11	0.0	4	0.0	0.0	0.0	0.0
Henry	216207	1.8	353.37	0.9	176.68	0.0	29	0.0	16	0.0	0.0	0.0	0.0
Huron	226253	4.0	821.75	2.3	472.51	0.0	9	0.0	16	0.0	0.0	0.0	0.0
Lake	31506	3.9	111.57	1.9	54.35	0.0	22	0.0	14	0.0	0.0	0.0	0.0
Lorain	119984	2.4	261.47	1.8	196.10	0.0	5	0.0	4	0.0	0.0	0.0	0.0
Lucas	78114	1.4	99.30	0.7	49.65	0.0	26	0.0	30	0.0	0.0	0.0	0.0
Marion	10875	4.0	39.50	2.9	28.64	0.0	14	0.0	7	0.0	0.0	0.0	0.0
Medina	67029	4.5	273.88	3.0	182.59	0.0	7	0.0	5	0.0	0.0	0.0	0.0
Mercer	113243	4.2	431.86	1.9	195.37	0.0	18	0.0	10	0.0	0.0	0.0	0.0
Ottawa	109893	2.4	239.48	2.0	199.57	0.0	29	0.0	15	0.0	0.0	0.0	0.0
Paulding	209229	1.9	360.96	1.5	284.97	0.0	5	0.0	3	0.0	0.0	0.0	0.0
Portage	6453	5.1	29.88	2.9	16.99	0.0	14	0.0	9	0.0	0.0	0.0	0.0
Putnam	234898	2.1	447.90	1.6	341.26	0.0	21	0.0	13	0.0	0.0	0.0	0.0
Sandusky	200353	3.2	582.15	2.0	363.84	0.0	27	0.0	19	0.0	0.0	0.0	0.0
Seneca	211346	3.5	671.66	1.6	307.04	0.0	13	0.0	3	0.0	0.0	0.0	0.0
Summit	2687	2.2	5.37	2.2	5.37	0.0	19	0.0	16	0.0	0.0	0.0	0.0
Van Wert	207628	2.6	490.17	1.1	207.38	0.0	10	0.0	6	0.0	0.0	0.0	0.0
Williams	176670	5.3	850.21	2.5	401.04	0.0	19	0.0	11	0.0	0.0	0.0	0.0
Wood	321204	1.6	466.65	0.7	204.16	0.0	22	0.0	9	0.0	0.0	0.0	0.0
Wyandot	135223	5.2	638.47	2.3	282.40	0.0	17	0.0	8	0.0	0.0	0.0	0.0
Michigan													
Hillsdale	134415	2.1	256.30	1.3	158.66	42.9	0	11.4	0	8.6	2.9	5.7	2.9
Lapeer	44271	1.3	52.26	1.0	40.20	30.9	0	11.3	0	6.5	3.5	2.2	0.0
Lenawee	336745	6.5	1987.47	2.7	825.56	20.0	0	6.7	0	9.5	8.6	2.9	3.8
Livingston	13250	1.6	19.25	1.4	16.84	22.5	0	17.2	0	7.4	3.7	2.5	0.0
Macomb	101199	1.0	91.89	0.6	55.13	12.1	0	8.3	0	12.8	5.2	13.8	7.2
Oakland	2940	1.4	3.74	1.0	2.67	17.1	0	10.7	0	12.1	9.3	8.9	7.5
Sanilac	195954	0.3	53.38	0.3	53.38	27.6	0	13.1	0	6.4	1.7	0.9	0.6
St. Clair	151228	0.4	54.93	0.3	41.19	27.6	0	9.5	0	6.1	4.1	3.4	1.4
Washtenaw	205288	2.6	484.64	1.8	335.52	16.7	0	14.7	0	10.9	7.7	6.4	8.3
Wayne	43770	1.2	47.69	0.6	23.85	22.9	0	13.3	0	12.0	9.6	9.6	10.8
Total	5,194,103		14,198.81		7,398.54								

Table 4. Reductions in labile and nonlabile particulate phosphorus and desorbable phosphorus in the Lake Erie Basin Counties of Ohio and Michigan with fertility management.

County	Excess Available Soil P (µg/g)	Phosphorus Reductions With Fertility Management (metric tons): Nonlabile Particulate Phosphorus: Present Conditions	Nonlabile Particulate Phosphorus: Max. Conserv. Tillage	Labile Phosphorus	Desorbable Phosphorus
Ohio					
Allen	5.25	1.85	0.75	0.46	0.05
Ashland	5.13	0.24	0.17	0.06	0.01
Ashtabula	2.15	0.11	0.10	0.03	0.00
Auglaize	4.40	0.58	0.26	0.15	0.01
Crawford	4.28	0.98	0.45	0.24	0.02
Defiance	4.53	0.01	0.38	0.15	0.02
Erie	7.45	0.69	0.33	0.17	0.02
Fulton	13.95	2.95	1.32	0.74	0.07
Geauga	3.10	0.00	0.00	0.00	0.00
Hancock	5.93	1.89	0.77	0.47	0.05
Hardin	2.93	0.05	0.02	0.01	0.00
Henry	9.08	1.28	0.64	0.32	0.03
Huron	5.58	1.83	1.05	0.46	0.05
Lake	7.35	0.33	0.16	0.08	0.01
Lorain	1.88	0.20	0.15	0.05	0.00
Lucas	12.05	0.48	0.24	0.12	0.01
Marion	4.20	0.07	0.05	0.02	0.00
Medina	2.48	0.27	0.18	0.07	0.01
Mercer	5.65	0.98	0.44	0.24	0.02
Ottawa	8.83	0.85	0.70	0.21	0.02
Paulding	1.63	0.23	0.19	0.06	0.01
Portage	4.70	0.06	0.03	0.01	0.00
Putnam	6.93	1.24	0.95	0.31	0.03
Sandusky	9.48	2.21	1.38	0.55	0.06
Seneca	3.03	0.81	0.37	0.20	0.02
Summit	7.33	0.01	0.02	0.00	0.00
Van Wert	3.25	0.63	0.27	0.16	0.02
Williams	6.08	2.07	0.97	0.52	0.05
Wood	6.10	1.14	0.50	0.28	0.03
Wyandot	4.98	1.27	0.56	0.32	0.03
Michigan					
Hillsdale	21.15	2.17	1.34	0.54	0.05
Lapeer	12.30	0.26	0.20	0.06	0.01
Lenawee	20.84	16.56	6.88	4.14	0.41
Livingston	13.83	0.01	0.09	0.03	0.00
Macomb	35.58	1.31	0.78	0.33	0.03
Oakland	34.21	0.05	0.04	0.01	0.00
Sanilac	10.61	0.23	0.23	0.06	0.01
St. Clair	14.96	0.33	0.25	0.08	0.01
Washtenaw	31.90	6.18	4.28	1.55	0.15
Wayne	40.41	11.13	5.57	2.78	0.28
Total		63.54	33.06	16.04	1.60

The greatest single source of P attributable to phosphate fertility levels is Lenawee County, Michigan (Table 4) which accounts for 26 and 21% of the nonlabile particulate P reductions under existing conditions and conservation tillage management, respectively. This county also accounts for about 25% of the labile and desorbable P load. Lenawee County has the highest cropland acreage of any of the counties in this analysis and the highest gross erosion rate (Table 3). It also has high available P soil test levels, as do most of the Michigan counties included here.

RATE OF UTILIZATION OF RESIDUAL AVAILABLE SOIL PHOSPHATE BY CROPS

In recent years, it has become apparent that many U.S. agricultural soils have available phosphate levels that are substantially higher than those required for most crops. This trend has resulted in more farmers applying annual rates of phosphate fertilizer which will maintain their present fertility levels. However, most maintenance applications continue to slowly increase available P levels in the soil, and many states recommend maintenance applications regardless of how high the available P level might be. A number of studies at state experiment stations have been investigating the ability of crops to utilize the residual fertility of soils high in available phosphate. These studies have shown (Cope and Khasawneh, 1981) that soils can be cropped for periods up to a decade before crops respond to further additions of P fertilizer.

The factors which control the rate of release of available phosphorus in soils are not well understood. Some soils which have a high retention capacity for phosphate are able to release phosphate over a long period of time, while soils with low retention capacity are more quickly depleted. The ability of a soil to supply P is also related to the total amount of phosphate in the soil that can be converted to available forms, and this may or may not be affected by the amount of phosphate applied previously. Also confounding the problem are the specific P requirements of different crops and the ability of the soil to supply P as fast as it is taken up by the crop during periods of peak demand.

Cox et al. (1981) have recently developed a model which attempts to predict the rate of release of residual P from soils with high available P levels. The model was calibrated and tested with data from seven long-term fertility studies on soils of varying P retention capacity: The model is given below:

$$\frac{dX}{dT} = - k(X - X_{eq}) \qquad [1]$$

$$X = X_{eq} + (X_{init} - X_{eq}) \exp(-kT) \qquad [2]$$

$$X_{init} = X_0 + b_1F + b_2F^2 \qquad [3]$$

$$X = X_{eq} + [(X_0 + b_1F + b_2F^2) - X_{eq}] \exp(-kT) \qquad [4]$$

X = available P soil test (kg/ha)

T = time (years)

k = decay constant (years^{-1})

X_{init} = initial soil test level (kg/ha)

X_0 = soil test level before P application (kg/ha)

X_{eq} = equilibrium soil test level (minimum value after continuous depletion) (kg/ha)

F = P application rate (kg/ha)

b_1, b_2 = linear and quadratic constants which relate change in soil test with P application.

The model computes the change in available P with time. Cox et al. (1981) found the decay constant (k) to be on the order of 0.1 to 0.3 years^{-1}. They also found that, for acid soils, the b_1 and k coefficients could be related by the following equation:

$$b_1 = \exp(-9.47k) \quad [5]$$

Cox et al. (1981) showed that half lives of available P in their experiments were from 3 to 10 years or longer. As more long term studies of residual P utilization are conducted, models such as the one given by Cox et al. (1981) may be useful in predicting the rate of depletion of residual available P. Nevertheless, the data would indicate that significant reductions in the levels of available P in Lake Erie Basin soils will only occur over a period of years, perhaps a decade or more.

ECONOMIC LEVELS OF PHOSPHATE FERTILIZATION OF GRAIN CROPS IN THE LAKE ERIE BASIN COUNTIES OF OHIO

The general purpose of this section was to analyze the economic use of phosphate fertilizers on grain crops in Ohio. Specifically, the objectives are:

1. To determine the present phosphorus application rates on corn, soybeans, and wheat in Ohio,
2. To develop a model which estimates the profit maximizing phosphorus application rates,
3. To apply this model to a representative sample of Lake Erie Basin counties in Ohio to determine Basin farmers' economic optimum phosphorus application rates, and
4. To compare present phosphorus application rates found in objective (1) with the farmers' economic optimum application rates found in objective (3).

By accomplishing objective (4), an estimate will be provided of the economic potential for "fertility management" as a best management practice in reducing Lake Erie phosphorus loadings. Some have questioned whether the high phosphorus fertilizer application rates being practiced by Basin farmers are economically beneficial to them. If phosphorus application rates are found to be excessive, then both farmers' welfare and Lake Erie water quality could be improved by reduced phosphorus application.

Only the Ohio portion of the Basin is used in this analysis. It is assumed that existing Ohio fertility practices and optimum application rates are representative of the entire Basin.

Existing Phosphorus Application Rates

Farmers and farm advisers tend to refer to phosphorus application rates in terms of phosphate (P_2O_5). To be consistent with this common usage, the report refers to all phosphorus rates in terms of their P_2O_5 equivalent.

The information concerning existing phosphate application is sparse; however, several sources of data provide an approximation of the rates. The Ohio Department of Agriculture annually publishes fertilizer sales information by county. For Ohio counties in the western Lake Erie Basin, 1978-79 phosphate sales averaged 69.5 pounds per cropland acre. For those counties in the Eastern Basin, 69.9 pounds per cropland acre was the average sales figure. This data is available only as total sales in each county. The amount of phosphorus sold for use on particular crops is unknown.

Duvick (unpublished report) surveyed corn producers throughout Ohio in 1978 to determine existing fertilization rates as well as other farm management practices. Results were reported by crop reporting district (Figure 6). Phosphate application rates on corn were 95 pounds per acre in District 1, 107 pounds per acre in District 2 and, 87 pounds per acre in District 3. The state average phosphate application rate was estimated to be 98 pounds per acre. Duvick's results indicate that phosphate application rates in District 1 are nearly the same as the state's average, rates in District 2 are above the state average, and rates in District 3 are substantially below the state average.

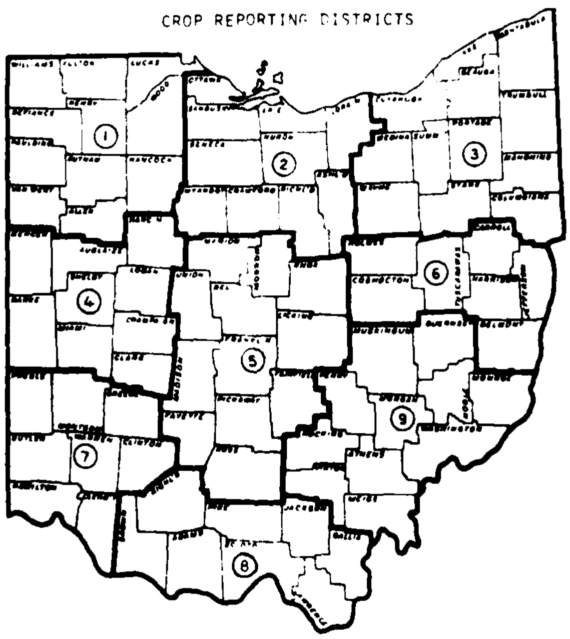


Figure 6. The crop reporting districts of Ohio.

State fertilization rate estimates for corn, wheat and soybeans are made annually by the Ohio Crop Reporting Service. Ohio estimates for 198[illegible] were that 98.1 percent of the corn acreage received phosphate at an average application rate of 78.9 pounds per acre; thus, the average application rate over all corn acres was

77.4 (Table 5). These estimates are unavailable for counties or crop reporting districts.

Table 5. Phosphate use on selected crops, Ohio, 1980.

Crop	Acres Receiving P_2O_5 (percent)	Rate per Acre Receiving (pounds)	Rate per Acre-All Acres (pounds)
Corn	98.1	78.9	77.4
Soybeans	47.5	37.5	17.8
Wheat	98.6	56.7	55.9

Phosphate application rates by crop and by crop reporting district are derived by combining the results of the Duvick study and Ohio Crop Reporting Service estimates. Duvick's estimates indicate that rates are proportionately higher in District 1 and lower in District 3 than the state average. Rates in District 2 are nearly the same as the state average. Combining these proportions with Ohio Crop Reporting Service estimates provides the estimates shown in Table 6.

Table 6. Phosphate use for selected crops by Crop Reporting District, Ohio, 1980.

District	Corn	Soybeans	Wheat
	pounds per acre		
1	75	17	54
2	85	19	61
3	69	16	50
State Ave.	77.4	17.8	55.9

These estimated rates probably err on the side of being lower than actual application rates. Using these rates, phosphate application rates would have averaged 48 pounds per cropland acre in 1980. Fertilizer sales data indicate that 69 pounds per cropland acre were sold. The use of fertilizer on other crops could explain some of this difference.

Economic Model

Inputs such as land, fertilizer, tractors, labor, buildings, and seed are combined by a known production technology to produce outputs such as grain. Production functions depict the relationship between output and inputs. Some inputs are varied and others are held fixed. A production function relating output to one variable input is shown in Figure 7. Through numerous observations, it has been observed that most production functions have similar characteristics.

Production functions exhibit the law of diminishing returns as illustrated in Figure 7. According to the law of diminishing returns, as additional units of an input are added with all other inputs held constant, output increases at a decreasing rate, reaches a maximum, and finally declines.

Diminishing returns in a production function are easily observed but are often overlooked by some agriculturalists. Many view the response of corn to fertilizer as not involving diminishing returns. That is, corn yield is a linear function of fertilizer application. A rule of thumb might say, "apply 0.8 pounds of nitrogen fertilizer per acre for every bushel of corn desired." Graphically this production function would be a linear function between the input and the output. Logically, such a relationship cannot exist regardless of the pounds of nitrogen applied, or farmers would be dumping tons of nitrogen fertilizer on each acre of corn ground.

Others view the production function as reaching a plateau at some point. That is, output increases linearly as more units of input are added, and then output reaches a plateau. A rule of thumb based on this kind of production function might state, "apply 1 pound of nitrogen fertilizer per acre for each bushel of corn desired up to 200 pounds of nitrogen, where yields level off." With much empirical testing over the years, few agricultural production functions have exhibited such linear behavior. Most exhibit a curvilinear relationship because of the law of diminishing returns.

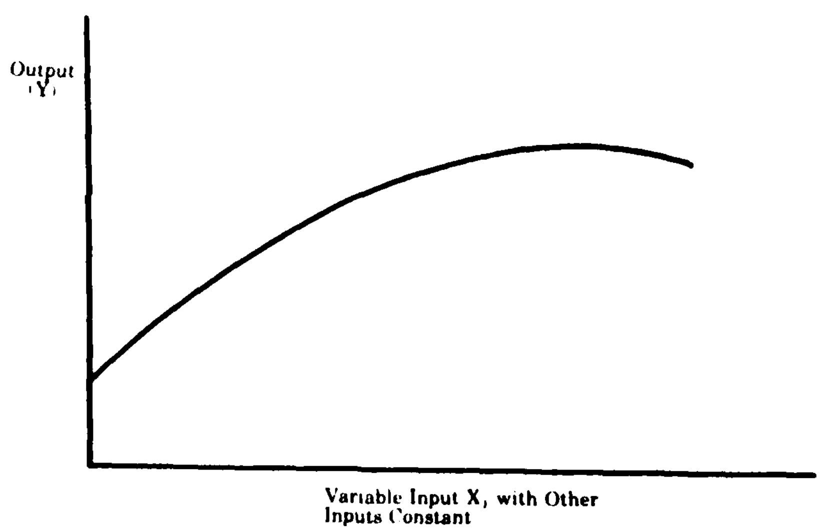


Figure 7. Production function with diminishing returns.

The concept used in finding optimum economic application rates is called "marginal analysis." It can best be described as the principle of adding additional units of an input (phosphate) until the cost of the last unit just equals the value of additional output (e.g., corn). Thus, two sets of information are needed to determine optimum application rates. First, the production function is needed. Secondly, the prices of the input (phosphate) and output (corn) are needed. Using both sets of data in economic analysis, it is possible to determine the most profitable application rate. If the price of corn is relatively high, the profit-minded farmer would tend to apply more phosphorus and produce more corn since the value of each additional unit of corn produced has increased. Conversely, if the price of phosphorus is relatively high, less phosphorus would be applied and less corn produced.

Research conducted by Johnson and Shepherd, Extension Agronomists, Ohio State University, provide production functions for this analysis. In their analysis crop yield is a function of two variables: soil test phosphorus level and phosphate application. Both variables exhibit diminishing returns. Those functions are given below for corn, soybeans and wheat:

Corn: $\log \frac{A-Y}{A} = -0.043$ (available P, lbs/ac) -0.0091 (P added lbs P_2O_5/ac)

Soybeans: $\log \frac{A-Y}{A} = -0.054$ (available P, lbs/ac) -0.0071 (P added, lbs P_2O_5/ac)

Wheat: $\log \frac{A-Y}{A} = -0.031$ (available P, lbs/ac) -0.010 (P added, lbs P_2O_5/ac)

A = 100% yield   Y = Observed yield

Complicating the analysis is the fact that phosphate application affects the soil test phosphorus level in future years. Thus, not only are crop yields affected in the year of phosphate application, but also future yields are affected. While this effect is not known with certainty the following assumptions were made in the analysis:

1. If phosphate application rates are greater than 20 pounds per acre, the soil test, phosphorus level increases in the first year following application by 10 percent of the amount of phosphate in excess of 20 pounds per acre. Thus, if the soil test phosphorus level is 25 pounds per acre, a phosphate application rate of 50 pounds P_2O_5 per acre increases the soil test phosphorus level to 28 pounds P per acre [25 + (0.10)(50-20)]. In succeeding years this increased soil test level decays at a rate we assume to be 20 percent per year. Thus in the above example, the second year following phosphate application would show the soil test fall to 27.4 [28-3(0.20)]. Although there is little good data on the rate of decay, 20% a year is probably an overestimation.
2. If phosphate application rates are less than 20 pounds P_2O_5 per acre, the future soil test phosphorus level declines by 20 percent of the amount of phosphate which is short of 20 pounds per acre. Thus, if the soil test is 25 pounds per acre, a phosphate application rate of 15 pounds per acre would reduce phosphate test levels to 24 pounds per acre in future years [25-(0.20)(20-15)].

Phosphate application must be viewed in a multiple year perspective. Not only are the current year's yields impacted, but also all future yields are affected. The optimum economic application rate occurs where adding an additional unit of input (phosphate) costs the same as the present value of this year's additional output (e.g., corn) plus all future years' changed output. In the analysis, future returns are discounted at a 12 percent discount rate to compute present values.

An example is used to clarify these concepts. Assume a field has a soil test phosphorus level of 25 pounds P per acre. Corn is to be grown. Phosphate is \$0.169 per pound and corn is \$2.36 per bushel (average 1978-79 prices). Using the Johnson and Shepherd production function, the economically optimum phosphate application rate is 91 pounds P_2O_5 per acre. At 91 pounds P_2O_5 per acre, the last pound of phosphate produces an additional 0.042 bushels of corn in the current year, an additional 0.01 bushels of corn in the second year, and continually decreasing additional corn in succeeding years.

Algebraically, the value of this marginal output (VMP) is the following:

$$\text{VMP} = \frac{\partial \text{ yield}}{\partial \; P_2O_5 \text{ application}} \cdot \text{price of corn} +$$

$$\cdot \; \frac{\partial \text{ yield}}{\partial \text{ soil test}} \cdot \frac{\partial \text{ soil test}}{\partial \; P_2O_5 \text{ application}} \cdot \frac{\text{price of corn}}{(i + k)}$$

where i is the discount rate and k is the decay rate for future soil test level increases. In this example,

$$\text{VMP} = 0.042(2.36) + 0.010 \; \frac{2.36}{0.12 + 0.20} \quad = \$0.173$$

The ninety-first pound of phosphate is returning a present value of \$0.173 and costing \$0.169. The ninety-second pound of phosphate is returning slightly less than \$0.169 and would not be applied.

Analysis of a Representative Sample of Basin Soils

The Ohio soil test summary data is selected as a representative sample of Basin soils. The summary reflects all soil samples submitted to the Ohio State University Soil Test Laboratory at Wooster. The summaries reported by Logan (1977) for 1976 were used in this analysis. Logan concluded that these "summary data appear to be a reasonable reflection of actual available P levels in Lake Erie Basin counties."

The distribution of soil test phosphorus levels for each county is shown in Table 7. For each county, the mean economically optimum phosphate application rate is estimated by combining this distribution with the economic model outlined previously. The following prices are used in the analysis:

	Average Ohio 1978-79 Price
Corn	\$2.36/bushel
Soybeans	\$6.52/bushel
Wheat	\$3.66/bushel
P_2O_5	\$0.169/pound

Table 8 illustrates the economically optimum phosphate application rates for several soil test phosphorus levels. These levels are used to represent the distribution of soil test phosphorus levels.

Table 7. Percent distribution of Ohio State Soil Test Laboratory available P results in Lake Erie Drainage Basin, by county, 1976 (Logan, 1977).

County	Available P (pounds per acre)					
	<10	10-19	20-29	30-59	60-89	>89
Maumee-Portage-Sandusky Basins						
Williams	2	11	17	41	19	11
Fulton	0	2	7	26	34	32
Lucas	1	6	7	30	26	30
Wood	1	6	13	47	23	9
Henry	0	6	7	42	29	16
Defiance	4	16	18	40	13	9
Mercer	1	10	14	46	18	10
Marion	2	13	21	44	14	7
Crawford	2	10	19	48	13	8
Sandusky	3	9	12	30	27	19
Paulding	4	24	26	38	5	3
Putnam	1	5	17	43	21	13
Hancock	1	9	14	47	21	9
Van Wert	2	17	16	50	10	6
Allen	1	12	15	46	20	7
Hardin	2	17	20	47	11	4
Auglaize	2	11	20	43	18	5
Wyandot	2	12	18	43	17	8
Seneca	2	16	22	42	13	3
Ottawa	2	8	15	31	29	15
N.E. Ohio (Lake Erie Drainage Basin)						
Erie	5	11	16	31	24	13
Huron	5	19	18	32	9	16
Lorain	9	28	19	34	5	4
Ashland	5	19	19	33	15	10
Medina	11	30	19	27	7	5
Ashtabula	19	27	16	27	8	3
Cuyahoga*	50	0	50	0	0	0
Summit	6	13	13	33	19	16
Portage	8	19	19	30	14	9
Geauga	11	27	20	27	12	4
Lake	14	29	10	10	22	14
Trumbull	12	27	15	32	8	5

Table 8. Economically optimum phosphate (P_2O_5) application rates for crops at selected soil test phosphorus levels.*

Phosphorus Soil Test (pounds per acre)	Corn	Soybeans	Wheat
5	175	185	133
15	133	123	105
25	91	67	77
45	21	—	23
75	—	—	—
100	—	—	—

*At 1978-79 price levels.

Finally, the mean economically optimum phosphate application rate for each county is listed in Table 9. Generally the Western Lake Erie Basin counties have lower optimum rates than Eastern Lake Erie Basin counties.

Optimum P_2O_5 rates for corn averaged about 41 pounds per acre in the Western Basin and about 65 pounds per acre in the Eastern Basin. Comparing these rates with actual phosphate use (Table 6), it appears that Western Basin corn farmers are applying phosphate in excessive amounts, on the average. Of course, not all Western Basin corn farmers are over applying. Some are probably under utilizing phosphate fertilizer, but the average phosphate application rate for corn appears to exceed the optimum rate by about 35-40 pounds per acre.

For soybeans the economically optimum P_2O_5 application rate averages about 29 pounds per acre in the Western Basin and about 52 pounds per acre in the Eastern Basin. Actual application rates for soybeans in the Western Basin are about 10 pounds per acre less than the economically optimum rate. In the Eastern

Table 9. Mean economically optimum phosphate application rate, by county.*

Maumee-Portage-Sandusky Basins	Optimum Application Rate Weighted Mean			N.E. Ohio (Lake Erie Drainage Basin)	Optimum Application Rate Weighted Mean		
	Corn	Soybeans	Wheat		Corn	Soybeans	Wheat
Williams	42.9	29.3	37.0	Erie	45.1	34.2	38.0
Fulton	15.3	8.1	14.1	Huron	57.7	45.3	48.1
Lucas	23.1	14.8	20.5	Lorain	77.9	64.3	63.9
Wood	32.0	18.7	28.8	Ashland	58.9	45.9	45.1
Henry	23.8	12.9	21.8	Medina	69.3	58.1	56.6
Defiance	53.6	40.0	45.4	Ashtabula	89.8	79.5	72.3
Mercer	38.0	24.3	33.5	Cuyahoga	—	—	—
Marion	49.8	34.4	42.8	Summit	47.2	36.5	39.6
Crawford	44.8	29.4	39.0	Portage	63.5	51.4	52.4
Sandusky	35.1	25.4	30.0	Geauga	79.6	67.4	64.8
Paulding	71.2	54.8	59.4	Lake	74.8	68.7	59.4
Putnam	33.6	20.2	29.9	Trumbull	77.7	65.9	63.4
Hancock	36.9	23.1	32.7				
Van Wert	51.7	36.0	44.5	Actual Use	69-77	16-18	50-56
Allen	41.6	27.4	36.3	Average†	64.6	52.2	51.3
Hardin	54.7	38.6	46.9				
Auglaize	46.0	31.3	39.7				
Wyandot	45.5	31.2	39.3				
Seneca	54.2	38.7	46.2				
Ottawa	35.0	24.3	30.2				
Actual Use	75	17	54				
Average†	41.0	28.6	36.9				

* At 1978-79 price levels.

† Average is computed by weighting each county's optimum application rate by the crop's acreage in the county.

Basin, actual application rates for soybeans average about 45 pounds per acre less than the economically optimum.

For wheat, actual and economically optimum phosphate application rates appear to be about the same. Western Basin wheat farmers may be applying about 10-15 pounds per acre more than the economic optimum. Eastern Basin wheat farmers are applying about 50 pounds per acre, which approximates the economic optimum.

Conclusion

There is some room for improvement in phosphorus fertilization. Fertilization practices vary substantially from farm to farm as to basic soil characteristics. Thus, the following generalizations do not apply to all farms in the Basin.

Specific fertilization improvements would be the following:

Western Lake Erie Basin

1. Reduce the average P_2O_5 rate on corn by at least 35 pounds per acre.
2. Increase the average P_2O_5 rate on soybeans by about 10 pounds per acre.
3. Reduce the average P_2O_5 rate on wheat by at least 10 pounds per acre.

Eastern Lake Erie Basin

1. Increase the average P_2O_5 rate on soybeans by about 45 pounds per acre.

THE EFFECTIVENESS OF AGRICULTURAL MANAGEMENT PRACTICES IN REDUCING PHOSPHORUS LOADS

This section examines the range of agricultural practices which may have some effectiveness in reducing the rural diffuse phosphorus load to Lake Erie. Many of these practices were designed for erosion control rather than nutrient management, but with erosion control there is always control of the particulate phosphate fraction and the dissolved P load may also be reduced.

The literature provides very little data on phosphorus reductions by the whole range of practices considered here, so a number of assumptions had to be made in order to calculate a P reduction. Costs were estimated from the literature and from current SCS figures, wherever possible.

Overall Assumptions

1. If the practices reduced sediment but did not reduce flow volume, soluble P was assumed not to change.
2. If the practices reduced sediment, it was assumed that reduction in total particulate phosphorus (TPP) was 90% of the sediment reduction.
3. Unless otherwise noted, TPP was assumed to be 80% of total P (20% was soluble P).
4. Calculations were made in English units. For the Lake Erie Drainage Basin on the U.S. side, a unit area total phosphorus load of 1.5 lb/ac was assumed for present conditions (condition where no phosphorus control practices were used). This is based on the PLUARG (1978), COE (1979) and Logan and Stiefel (1979) reports.

5. Costs were based on values used in Ohio by the Soil Conservation Service and provided by Mr. Joe Harrington, SCS State Engineer, Columbus, Ohio; literature values from various sources.

Specific Assumptions

1. **No Till** - An 80% reduction in soil loss was assumed. See overall assumptions for P reduction with no change in runoff volume. Although Forster (1978) has shown that there are little or no costs to the farmer when no till is used on recommended soils, there is probably an initial cost to society for educational and demonstration programs, and technical assistance required to achieve rapid implementation. An arbitrary cost of $1/acre was chosen and this probably represents a maximum for this practice.

2. **Cover Crop** - A 10% soil loss reduction for cover crop was based on the reduction in the USLE "C" factor when cover crop was seeded into a row crop. See overall assumptions for phosphorus reduction with no change in runoff volume. Costs were obtained from SCS estimates of the South Branch Cattaraugus Creek, N.Y. (unpublished report).

3. **Critical Area Seeding** - A 95% reduction in soil loss was based on USLE "C" factors for pasture and woodland versus row crop. Costs were obtained from SCS estimates for Cattaraugus Creek (unpublished report) and checked by calculating the loss in revenue by shifting from row crops. Flow volume was assumed to decrease somewhat, and soluble P concentrations were assumed to remain the same or increase slightly. Therefore, a 50% reduction in the soluble P load was assumed. Since the total P load under standard conditions

was assumed to be 1.5 lb/ac, and it was also assumed that 20% of that was soluble, then the soluble P load under standard conditions would be 0.3 lb/ac.

4. **Contour Stripcropping** - Assumes a 50% soil loss reduction based on USLE P factor. It was also assumed that runoff volume would decrease somewhat, so a 25% reduction in soluble P was used. The cost data was obtained from SCS estimates for Cattaraugus Creek (unpublished report) and from Haith and Loehr (1979).

5. **Diversions** - Costs and sediment reduction estimates were provided by Mr. Joe Harrington, SCS State Engineer and others on the Ohio SCS state staff. The figures were based on a cost of $2/foot for the diversion ditch and with the assumption that the diversion would protect a length 300 ft from the ditch. The lifetime of the ditch is assumed to be 10 years and annual maintenance costs are included. The 25% reduction in sediment load is based on the analysis of Haith and Loehr (1979). Because the diversion ditch can be expected to reduce runoff velocity and perhaps volume, a 25% reduction in soluble P was assumed.

6. **Grassed Waterways** - Figures were provided by Ohio SCS for conditions in NW Ohio. Cost per acre of waterway was estimated to be $3000 and it was assumed that each waterway (1500 ft x 30 ft) would drain an area of 75 acres. This gave an overall cost per acre protected of $40. Sediment load reduction was based on USLE calculation, Haith and Loehr (1979) and unpublished research by Alberts, Neibling and Moldenhauer, Purdue University. It was assumed that waterways would have no effect on runoff volume or soluble P.

7. **Vegetative Filters** - Cost estimates were made by Ohio SCS state staff. Cost per acre of vegetation was $300 and it was assumed that the strip would be 20 feet wide along the channel and would control sediment from an area 500 feet away from the channel. This gave a cost per acre of $13. The sediment and phosphorus reduction figures are the same as for grassed waterways.

8. **Runoff Control Structures** - It was estimated that each structure cost $1000 and controlled an area of 10 acres. The major protection afforded by this practice is gulley or streambank erosion. The streambank erosion percentage was based on the PLUARG studies by Mildner (1978). It was assumed that this practice would have no effect on soluble P.

9. **Terraces** - Costs were estimated from those of Haith and Loehr (1979). Sediment reduction estimated from USLE and various research results. A 50% reduction in soluble P is assumed. These are based on several field experiments as reported by Haith and Loehr (1979).

10. **Tile Drainage** - The annual costs of tile drainage were based on an installation cost of $500/acre depreciated over 40 years and including an annual maintenance cost. The sediment and phosphorus reduction figures are based on the monitoring data of Logan and Stiefel (1979).

11. **Streambank Protection** - The costs of streambank protection were estimated by Ohio SCS state staff. They assumed that 1 acre of vegetation would protect 20 acres of cropland. Sediment reductions were based on the data of Mildner (1978).

12. **Manure Storage and Spreading** - The costs associated with these practices are highly variable depending on the particular system used, and so a range was used. Cost figures were obtained from White and Forster (1978) and Dr. R. K. White, Ohio State University. Effectiveness for phosphorus control was obtained from White and Forster (1978), USEPA (1979), Young (1974) and Young and Holt (1977).

13. **Barnyard Runoff Control** - Phosphorus loads and reductions were determined from USEPA (1979) and Young et al. (1980). Costs were provided by Dr. R. K. White, Ohio State University.

14. **Fertility Management** - The phosphate reductions achievable by fertility management were based on the assumption that available P levels were 30% above the P response level and that this percent reduction in available P would lower the total P load by 3%.

15. **Fertilizer Placement** - The $5/acre annual cost was estimated to be the cost of specialized equipment for fertilizer injection or placement with the seed. It was estimated that 0.5 lb P/ac might be lost by surface broadcast of P fertilizer on no till. It was assumed that 90% of this load could be reduced by placing the fertilizer below the soil surface.

Table 10 gives the reductions in sediment and phosphorous losses with the various agricultural management practices, and the costs per pound of phosphorus loss reduced. These estimates are intended as approximate values only, and can very significantly from region to region, and as a function of the assumptions used.

Table 10. Costs and sediment and phosphorus reductions with various agricultural management practices.

Practice	Annual Cost $/acre	Sediment Reduction %	Total Phosphorus Reduction %	Total Phosphorus Reduction lb/ac*	Annual Cost of Reduction $/lb P	Assumptions	References
No Till	1	80	60	0.9	1	1.5 lb P/ac loss	Logan & Adams (1981)
Cover Crop	15	10	7	0.1	150	"	Wischmeier and Smith (1978)
Critical Area Seeding	200	95	78	1.2	167	"	Wischmeier and Smith (1978)
Contour Stripcropping	25	50	41	0.6	42	"	Wischmeier and Smith (1978)
Diversions	50	25	23	0.3	167	Each foot protects 300 ft.	SCS-Columbus
Waterways	40	70	50	0.8	50	1 per 75 acres; 1.5 lbs P/ac loss	SCS-Columbus
Vegetative Filters	13	70	50	0.8	16	1 acre will protect 23 acres	SCS-Columbus
Runoff Control Structures	5	5	4	<0.1	156	1 per 10 acres	SCS-Columbus
Terraces	40	90	75	1.1	36		Wischmeier and Smith (1978)
Tile Drains	55	10	8	0.1	458	Based on field observations	Logan & Stiefel (1979)
Streambank Protection	50	5	4	<0.1	833	1 ac protects 20 ac	SCS-Columbus; Mildner (1978)
Manure Storage and Spreading	10–100	0	75	1.5	7–67	1 per 150 acres	Dr. R. K. White
Barnyard Runoff Control	5	?	75	2.0	3	1 per 150 acres	Dr. R. K. White
Fertility Management	0	0	3	<0.1	0	On average, available P levels are 30% above response level	Dr. T. J. Logan
Fertilizer Placement	5	0	90	0.5	11	0.5 lb P/ac loss	Dr. T. J. Logan

*Rounded to the nearest 0.1 lb/ac. Percent reduction based on nearest 0.01 lb/ac.

Their primary value, however, is in determining the relative cost effectiveness of the various practices. No attempt was made at this stage to determine the present use or suitability of all of these practices in the Lake Erie Basin, but some general observations can be made. Since the Lake Erie Basin is dominated by cultivated crops, those practices involved in grain crop production would be most important. The most cost effective of these would be phosphate fertility management, phosphate fertilizer placement and conservation tillage (including no till). Of these, conservation tillage will have the greatest impact on the total phosphorus load to the lake.

In parts of the watershed with high concentrations of livestock, manure storage and spreading and barnyard runoff control may be as important or more important than practices associated with grain crop production.

Many of the other practices such as terraces are not commonly used in the Lake Erie Basin, while others such as waterways and strip cropping are primarily used for erosion control. Their high cost per pound of phosphorus controlled make them less effective as P control practices compared to conservation tillage or fertility management.

CONCLUSIONS

1. Available phosphorus levels in agricultural soils in the Ohio and Michigan counties of the Lake Erie Basin have continued to increase steadily since the 1960's. Many soils are testing well above the level of fertilizer response for grain crops.
2. Reductions of available P levels to the sufficiency level for Lake Erie Basin soils will have a small impact on total phosphorus loads to Lake Erie compared to the reductions that can be achieved with conservation tillage. However,

fertility management is required to slow or halt the trend for build-up of excessive levels of available phosphorus in Basin soils.

3. An economic analysis of phosphate fertilizer requirements for corn, soybeans and wheat in the Lake Erie Basin counties of Ohio showed that corn and, to a lesser extent, wheat were overfertilized with phosphate in NW Ohio counties while soybeans were underfertilized in both NE and NW Ohio.

4. The effectiveness of various agricultural management practices in reducing diffuse phosphorus loads was examined. Conservation tillage and fertility management were cost-effective practices for the Lake Erie Basin.

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